HIGH ALTITUDE OBSERVATORY
Boulder, Colorado

24 March 1966

National Aeronautics and
Space Administration
Office of Research Grants and Contracts
1520 H Street, N.W.
Washington, D. C. 20546

[redacted]

Reference: SC-NsG-726/06-07-006

Subject: Status Report No. 3 for NASA Grant NsG-726

Gentlemen:

This letter constitutes Status Report No. 3 under NASA Grant NsG-726 for the period 1 July 1965 through 31 December 1965. The purpose of this grant is to provide new laboratory wavelength identifications and energy level determinations to aid in the identification of many unknown lines in the vacuum ultraviolet solar spectrum.

Progress

The theta-pinch plasma machine has been put into operation by Dr. House as a light source for the production of radiation from highly ionized coronal-type ions. The emission lines from impurity elements added to the plasma can be observed in the vacuum UV and x-ray regions of the spectrum, a range from about 10 to 1100 A. The goal of this experiment is to supply new atomic-energy-level data to help complete the identification of unknown lines in the rocket spectrum of the corona.

The light source may be briefly described as an electrodeless, theta pinch discharge powered by a 45-kilojoule, 20-kv, energy-storage capacitor bank. When the bank is discharged a current of 1.5 Ma flows through a single turn coil. Inserted into this coil is a ceramic discharge tube through which flows a mixture of hydrogen at a pressure of 50 μ, along with 3 to 5 μ of the impurity gas whose spectrum is to be analyzed. The current through the coil produces an axial magnetic field of about 80 kG which compresses and heats the plasma to 200 to 500 ev.

Two operational characteristics of this machine are of prime importance in the production of coronal-type spectra. First, a relatively high-purity plasma has been attained. It is particularly helpful in the analysis of the spectra to know that the level of intrinsic impurity is low enough so as not to dominate the spectra and thereby overwhelm or interfere with the spectra of impurities intentionally added for analysis. In our previous work on a higher energy plasma source at Los Alamos the ever-present, strong background spectrum presented difficulties in analysis which we are now able to avoid.

The second feature of the machine which is of major importance is that it exceeds the efficiency of the initial design estimates. It has been established through a measurement of the inductance of the circuit components that 82% of the energy stored in the capacitors is transferred to the coil. This is a high efficiency for this size and type of machine, and it is attained through minimizing the stray inductance in the circuit. The stray inductance of the system excluding the coil is 5.7 nanohenries, while the inductance of the coil is 25.9 nanohenries.

After the machine was completed, debugged, and tested, initial data were taken which proved productive. Some of these will be described below. Following this period of initial operation, manufacturer's errors in the main components of the system (capacitors and ignition switches), became evident, and these components were replaced, which caused a significant down-time. As the report period draws to a close, the system is being readied for a new start-up. When we resume operation, we are prepared to carry out some of the diagnostic experiments to establish the physical properties of the plasma, and to continue on the main goal of the program, which is production and analysis of highly ionized spectra.

Several of the diagnostic tools have either been constructed or are still in the shop. A two-channel continuum x-ray monitor has been built and calibrated by Blake. This instrument will be used to determine the temperature of the plasma through a measurement of the bremsstrahlung emission curve below 20 A. Two instruments to be utilized for the electron-density measurement are under construction by Wagner. The first is a Fabry-Perot laser interferometer in which the fringe shift produced by a laser beam traversing the plasma is measured and, through the index of refraction, related to the electron density. Another apparatus being constructed for electron-density measurement involves the determination of the absolute intensity of the continuum in the visible region of the spectrum. This measurement, coupled with an independent measurement of the temperature, will yield electron density. In addition to these diagnostic tools, the neutron monitor and x-ray survey camera have been built by Blake. The x-ray spectrometer is still under construction. This instrument will be used to observe the emission lines in the wavelength range below 100 A, thus giving a complete coverage of the spectrum from approximately 10 to 1100 A when used in conjunction with the vacuum UV spectrograph.

During the initial period of operation of the theta-pinch plasma machine, the diagnostics in use included a single-frame image converter camera and an x-ray pinhole camera. With the image-converter photographs we were able to observe the compression of the plasma and the onset of any instabilities which disrupt the confinement, or any drifts which force the plasma toward the containing wall. The x-ray pinhole pictures of the plasma, which had to be accumulated over many discharges, showed a stable, well defined, symmetric emitting volume on the axis of the discharge tube.

The new data obtained by Deutschman with the Hinteregger vacuum spectrograph fill some of the gaps in isoelectronic sequences which end on coronal-type calcium ions. Specifically, 30 new lines in the spectrum of S IX and X

[redacted]

and Cl IX, X and XI have been identified.[2] These lines are inner-shell resonance lines between configurations $2s^2 2p^n$ - $2s2p^{n+1}$ where n = 3, 4 and 5. The same transitions in Ar X, XI, and XII have also produced an additional 15 lines. These lines of argon were just recently reported in the literature. All of our internal consistency checks lead us to believe that we have more accurate wavelengths on these argon lines. In addition to the above, five new lines in the sodium-like spectrum of Cl VII were discovered originating on higher principal quantum number levels previously observed.

The new energy levels up through the spectrum of argon allow improved extrapolations for the ground-term splittings of Ca XII, XIII, and XIV. However, by improving the heating in the plasma we hope to be able to measure directly the ground-term splittings of these ions. In the spectra produced so far Ar XII, with an ionization potential of 539 ev, represents the highest ionization yet observed in our plasma source. If we are to produce, say Ca XIV with an ionization potential of 727 ev, then we must increase the temperature of the plasma. Two improvements will be made to the theta pinch which we hope will increase the heating. First, the energy of the pre-ionization bank is being increased. This preionization bank is discharged and allowed to ring out before the main 45-kilojoule bank is fired. The purpose of this is to produce initially a highly ionized plasma so the energy of the main bank will be put to most effective use, so that the energy will be used in heating the plasma rather than ionizing the hydrogen. The energy in this new preionization bank is 2800 joules at 20 kv compared to the 400 joules used previously. Second, we will also add a reverse bias capacitor bank. This system will be discharged before both the preionization and the main bank. Here the purpose is to insert a magnetic field into the plasma in reverse polarity to the field produced by the main bank. The magnitude of the magnetic field in the reverse bias bank will be of the order of 2 to 8 kG compared to the 80 kG of the main bank. The presence of the reverse bias field has been proved to increase the final heating through the incompletely explained phenomenon of annihilation of magnetic field lines.

In our work so far we have developed the view that the best way to analyze the spectra is to start in an isoelectronic sequence of astro-physical interest at the point where the accumulated data cease to exist. From there we attempt to extend the sequence experimentally step by step. This is in contrast to the usual technique of extending the data by theoretical extrapolations, which are frequently proven to be greatly in error. With the theta pinch and the high-voltage spark source we have a sufficient range of energy available to produce a wide range in ionization. Most important, these sources appear to be ideally suited to generate spectra similar to that of the corona. These spectra are needed to fill the gaps in data in Charlotte Moore's tables of atomic energy levels.

In conjunction with the experimental work the theoretical program based on a Hartree-Fock computer calculation has begun. Davies-Jones is carrying out this work. The goal is to provide purely theoretical energy-level calculations that can be compared with the experimental results.